

AD-A038 988

AIR FORCE GEOPHYSICS LAB HANSCOM AFB MASS
MAGNETIC FIELD RECONNECTION IN THE FLARE OF 18:28 UT 1975 AUGUS--ETC(U)
JUL 76 R C CANFIELD, R R FISHER
AFGL-TR-77-0011

F/6 3/2

UNCLASSIFIED

NL

1 OF 1
AD
A038988



END

DATE
FILMED
5-77

AD A 038988

MAGNETIC FIELD RECONNECTION IN THE FLARE OF 18:28 UT 1975 AUGUST 10

RICHARD C. CANFIELD AND RICHARD R. FISHER

Sacramento Peak Observatory, Air Force Geophysics Laboratory, Sunspot, New Mexico

Received 1976 July 6; revised 1976 September 20

ABSTRACT

We discuss observations of the flare of 18:28 UT, 1975 August 10 made with the Sacramento Peak Observatory 512 diode array, which simultaneously measures photospheric magnetic fields, photospheric and chromospheric velocities, and chromospheric brightness in several lines. The observations suggest triggering of the flare by emergence of new magnetic flux, as well as the geometry of the reconnected field during the flare. We discuss the implications of our observations regarding the site of the initial instability, as well as the relationship to X-ray observations.

Subject headings: Sun: flares — Sun: magnetic fields

I. INTRODUCTION

The observations discussed in this paper are of particular interest because they confirm and extend many aspects of a recent empirical flare model. This model, the *emerging flux model*, has been discussed by Canfield, Priest, and Rust (1974) and Heyvaerts, Priest, and Rust (1976), called Papers I and II below. The emerging flux model incorporates a specific sequence of events in a model of a typical flare. This sequence is: First, a new magnetic field emerges below an existing active-region neutral-line field system. (Rust 1975 has recently reviewed the observational evidence for the emergence of such new flux in the typical evolution of active centers.) Once this new field emerges, a quiescent current sheet forms between the existing and emerging field systems. At some point an instability sets in, and rapid reconnection between the two field systems ensues. This causes rapid heating and particle acceleration along the field lines of both systems. As a result, the chromosphere initially brightens at three points. Two of the three initial chromospheric brightenings occur at the foot points of reconnected field lines in the old neutral-line field system (see Paper I, Fig. 1 or Paper II, Fig. 6). The third initial chromospheric brightening is in the emerging flux region. The structure of this brightening has not been resolved previously, but such an observation is reported below. For further detail, we refer the reader to Papers I and II.

II. OBSERVATIONS

We report observations of the flare of 1975 August 10, 18:28 UT which took place in McMath region 13790 at apparent longitude W 18 and latitude N 08. These observations were obtained by the so-called flare-trap program, which uses the 512 diode array (Dunn, Rust, and Spence 1974; Rust and Bridges 1975) in the echelle spectrograph of Sacramento Peak Observatory's vacuum tower telescope (Dunn 1969, 1971). This instrument permits the essentially simultaneous digital measurement of intensity, velocity, and longitudinal magnetic field with high temporal resolution and moderate

spatial resolution. The data base of the present event consists of digital measurements every 15 s over an area 2×2 arc minutes with 2×2 arc second spatial resolution of (1) intensity of $H\alpha$ line center, $H\alpha \pm 0.6 \text{ \AA}$, $H\alpha - 1.2 \text{ \AA}$, $Fe \text{ I } \lambda 8468$ ($g = 2.5$), $Fe \text{ I } \lambda 5576$ ($g = 0$), $Ca \text{ II } \lambda 8542$, $He \text{ I } \lambda 10830$, $\lambda 10830 \pm 0.6 \text{ \AA}$, and $\lambda 10830 - 1.6 \text{ \AA}$; (2) longitudinal magnetic field in the photosphere derived from the wings of $Fe \text{ I } \lambda 8468$; (3) velocity derived from $Fe \text{ I } \lambda 5576$, $H\alpha$, and $He \text{ I } \lambda 10830$. Our data on this event cover the time intervals 15:49:45 to 16:00:45 UT and 18:28:00 to 19:58:00 UT. The interruption was caused by clouds, which precluded observations of the immediate preflare motions and perhaps the first 15 s of the $H\alpha$ flare.

a) Emerging Magnetic Flux

We now consider the observational evidence for emerging magnetic flux. The top row of Figure 1 (Plate L8) compares the sunspot intensity pattern at 15:49:45 UT with that at 18:28:00 UT, near the beginning of the $H\alpha$ flare. Many evolutionary changes in spot structure can be seen. Among them, the most pronounced is indicated by the arrow in the 18:28 image. Just left of the arrow is a sunspot that was absent at 15:49:45. Reference to the simultaneous magnetogram in Figure 1, row 2, shows that this spot has black polarity. To the left of this spot is a complex of spots of white polarity. Comparison of both the magnetograms and the spot intensity structures shows that this area also grew in size between 15:49:45 and 18:28:00. Together, these two areas appear to play the role of the emerging flux envisioned in Papers I and II. That the magnetic flux has increased in this region is clear from the data presented in Figure 1. Furthermore, this increase has taken place in an area straddling a neutral line; the relationship between the $H\alpha$ flare and magnetic neutral lines will be discussed below. Here we only wish to point out that a rather well-defined neutral line exists, running nearly vertically in the upper part of Figure 1, but it becomes much more complex near the site of the emerging flux. The tendency for flares to

AU NU.
DDC FILE COPY

occur in complex magnetic regions is a well documented observational fact (Rust 1975).

b) *Three-Point Initial Brightening and Loops*

Next we turn to the evidence for occurrence of the initial brightening at three points. We have no observations in the interval 16:01 to 18:27 UT, due to clouds. Useful observations began again at 18:28 UT. At this time the H α flare appears to have just begun. In the H α intensity image (Fig. 2 [Pl. L9], row 1) at 18:28, the three brightest points are indicated by arrows. These three initial brightenings can also be located in both the simultaneous H α red-wing images (row 2) and velocity images (row 3), being dark in the latter.

In Papers I and II it is proposed that the three initial bright points observed in the H α in this flare, as well as in many others, are a consequence of the geometric structure of the two different field systems that are being reconnected in the flare. In this flare, the upper and lower brightenings are thought to be the chromospheric foot points of lines in the existing active-region neutral-line field system. The central brightening is in the emerging flux region identified above in § IIa. These features are compatible with the geometry of the field proposed in Papers I and II, to which the reader is referred for further detail.

The middle brightening, associated with the emerging flux region, is of particular interest. In the H α image at 18:28 it is the largest and brightest of the three initial bright points. However, in the H α red-wing intensity image it is much more unique. It appears to be marginally resolved into an arcade of small loops, whose shape resembles that of a "quonset hut," and whose longitudinal axis is nearly vertical. The arcade is probably composed of several loops, not individually resolved, whose projected dimensions may be inferred from the lower end of the arcade to be about 4–6 arc seconds in thickness and 12–14 arc seconds in length. The entire arcade in projection fills an area with vertical and horizontal dimensions of 30 by 12–14 arc seconds; we identify the latter with the length of the individual loops. The loops appear to connect the white-polarity part of the emerging magnetic flux region with isolated pieces of dark polarity to its left. The loops are brightest at their tops, where bright knots of size about 4 arc seconds appear.

The velocity images derived from both H α and λ 10830 also show the loops. Only the H α velocity is shown here, in Figure 2, row 3. The loops can be seen as dark features at 18:28. In such velocity displays, which are formed by subtracting wing intensities, there is always an ambiguity in the sign of the velocity; a dark feature may be due to a blueshifted absorption feature or a redshifted emission feature. Examination of the actual blue-wing, line-center, and red-wing intensity distributions helps resolve this uncertainty. We tentatively conclude that the loops are a redshifted emission feature. It is of interest below that the entire loops are seen in the velocity image, not just the foot points at the bottom of the loops.

The emission loops are very short-lived. They are

rapidly lost in the widening flare region, and are no longer visible after 18:30. More recent diode-array observations, not yet reduced, imply that such loops may be quite common, but may be observable only with at least moderate spatial ($2'' \times 2''$) and temporal (30 s) resolution in addition to off-band capability in H α or λ 10830 and the proper aspect angle. Our observations indicate that both temporal resolution and off-band capability are particularly important.

III. DISCUSSION

We interpret these observations in the following manner, consistent with the emerging flux model: New flux emerges near an active-region neutral-line field system. Reconnection occurs between the emerging field system and the older field system. This reconnection region is then common to both systems. Material is heated to chromospheric temperatures, or cools to chromospheric temperatures, in parts of both the new system (the bright loops) and the old system (the entire brightening along the neutral line, starting with the upper and lower initial brightenings). Later in the flare, reconnection involves much more of the old system, hence the brightening all along the neutral line, where the old field system intersects the chromosphere.

Aside from the fact that this flare shows many of the observational features incorporated into the emerging flux model, we wish to single out two salient aspects of the observations: (a) their implications concerning the location of the initial instability, and (b) the similarity between the observed H α loops and recently reported loops seen in soft X-rays.

a) *The Site of the Initial Instability and Reconnection Region*

In the emerging flux model it is proposed that reconnection begins at the interface between existing and emerging field systems. The primary observational evidence for this is the three-point initial brightening. The present observation provides another piece of evidence. The location of the loops observed at 18:28 is near the edge of the emerging flux region. Our interpretation is thus that these loops outline magnetic field lines connected to one polarity of the emerging field system, *after reconnection*. An interesting observation, in our view, is that the entire loops are redshifted, apparently moving downward as a whole. This is compatible with the emerging flux model, since these loops are envisioned to be below the reconnection region. The new implication is that, whereas the material above the reconnection region, which is often but not always the site of a filament, moves upward in the initial stages of a flare, the material below the reconnection region—the loops in this case—moves downward. This is consistent with the idea that the pressure increase due to heating in this reconnection region is causing motions away from the region, forcing overlying material upward and underlying material downward.

On the basis of several arguments, Svestka (1973) argues that the height of the flare origin is approximately 4000–7000 km above the photosphere. This is in good

agreement with our observation, which places the flare origin at the top of the loops, or about 5000 km height, assuming an inclination of about 45° between the plane of the loops and the line of sight.

b) Relationship to Previously Observed X-Ray Loops

Soft X-ray emission from this flare was detected by SMS-1 GOES, in both 0.5–4 Å and 1–8 Å bands (*Solar-Geophysical Data* 1975). In the 1–8 Å band emission began at 18:24 UT. The flux reached a maximum value at 18:32, 1.3 orders of magnitude greater than its initial value. Our observation of H α loops falls centrally in the rising period of the soft X-rays. Most of the contribution to the soft X-rays usually detected in flares is known to come from loops (Vorpahl *et al.* 1975). The X-ray emission observed therefore strongly implies that X-ray loops existed at the same time as the H α loops. According to Vorpahl *et al.* (1975), these loops have characteristic lengths in the range 5–20 arcsec and widths of 5–10 arcsec, essentially identical to the 12–14 arcsec length and 4–6 arcsec thickness of the H α loops observed here.

It therefore seems likely that two quite different types of geometric relationships exist between the volumes emitting in X-ray and H α . In one case, as envisioned in the emerging flux model and that of Kahler, Petrasso, and Kane (1976), based on X-ray data, H α is bright only at the foot points of loops that are visible over a considerable fraction of their length in X-rays. In our view, this may be responsible for the upper and lower initial brightenings in H α in the present observations, as well as in two pairs of bright points in H α observed between 18:45 and 19:05 UT.

On the other hand, a different relationship between X-rays and H α is suggested for the loops. Here the fact that the scale of the H α loops is so similar to

previously observed X-ray loops suggests that the H α and X-ray loops might be adjacent or concentric flux tubes, at low and high temperatures, respectively. In this picture we envision the H α loops as having once been hot, and subsequently having cooled down to H α emitting temperatures, having been disconnected from the reconnection region, the heating source. Alternatively, they may be loops that were reconnected very early in the reconnection process, never having been heated appreciably above typical chromospheric temperatures.

c) Future Directions

The present observations suggest that the temperature structure along the magnetic field lines that define the initial H α loops may be quite different from that along the field lines that connect the reconnection region to the upper and lower initial chromospheric brightenings. For instance, the observed H α loops may no longer have an important heating source anywhere along the loops. On the other hand, the upper and lower initial brightenings may still be connected to the heating source, so that heating by nonthermal particles or conduction from hotter parts of the loop may play an important role. It would then be of considerable interest to have observed line profiles for strong chromospheric and transition region lines, with sufficient spatial information to distinguish the two different structures discussed above. Theoretical modeling efforts on the temperature and density structure of these two different situations would give some idea of what one might expect.

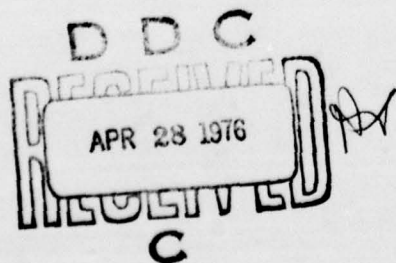
We wish to thank George Simon, Charles Bridges, and Richard Hansen for contributions in the course of this work.

REFERENCES

- Canfield, R. C., Priest, E. R., and Rust, D. M. 1974, in *Flare-Related Magnetic Field Dynamics*, ed. Y. Nakagawa and D. M. Rust (Boulder, Colorado: NCAR) (Paper I).
 Dunn, R. B. 1969, *Sky and Tel.*, **38**, 1.
 ———, 1971, *The Menzel Symposium on Solar Physics, Atomic Spectra and Gaseous Nebulae*, ed. K. B. Gebbie, NBS Spec. Pub. 353 (Washington: Govt. Printing Office), p. 71.
 Dunn, R. B., Rust, D. M., and Spence, G. W. 1974, *Instrumentation in Astronomy, II*, *SPIE Journal*, **44**, 109.
 Heyvaerts, J., Priest, E. R., and Rust, D. M. 1976, preprint (Paper II).
 Kahler, S. W., Petrasso, R. D., and Kane, S. R. 1976, preprint.
 Rust, D. M. 1975, Paper presented at Flare Buildup Study Workshop, 1975 September.
 Rust, D. M., and Bridges, C. A. 1975, *Solar Phys.*, **43**, 129.
Solar-Geophysical Data, No. 373, Part I, p. 27 (1975 September), (Boulder, Colorado: U.S. Department of Commerce).
 Svestka, Z. 1973, *Solar Phys.*, **31**, 389.
 Vorpahl, J. A., Gibson, E. G., Landecker, P. B., McKenzie, P. L., and Underwood, J. H. 1975, *Solar Phys.*, **45**, 199.

RICHARD C. CANFIELD: Dept. of Physics, Code C-011, University of California, San Diego, La Jolla, CA 92093

RICHARD R. FISHER: High Altitude Observatory, P.O. Box 3000, Boulder, CO 80303

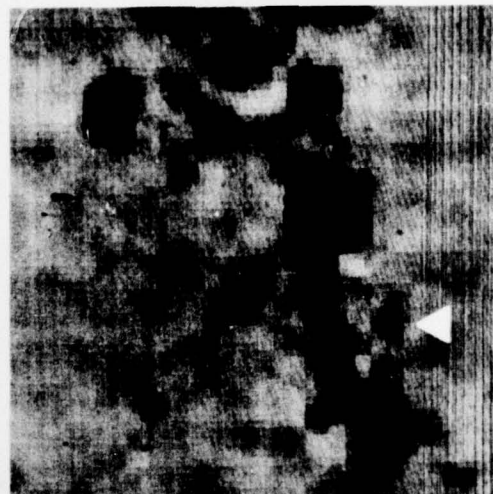


A 20	DATE	1976	TIME	1
	BY			
	DISTRIBUTION/AVAILABILITY CODES			
	<input type="checkbox"/> UNCLASSIFIED <input type="checkbox"/> CONFIDENTIAL <input type="checkbox"/> SECRET			

15:49:45

18:28:00

I



B



FIG. 1.—Observations of the quasi continuum intensity near $H\alpha$ (*top row*) and longitudinal magnetic field (*bottom row*) before (15:49:45 UT) and during (18:28) the flare of 1975 August 10. North is 70° clockwise from the vertical. (Sacramento Peak Observatory, Air Force Geophysics Laboratory photograph.)

CANFIELD AND FISHER (*see* page L149)

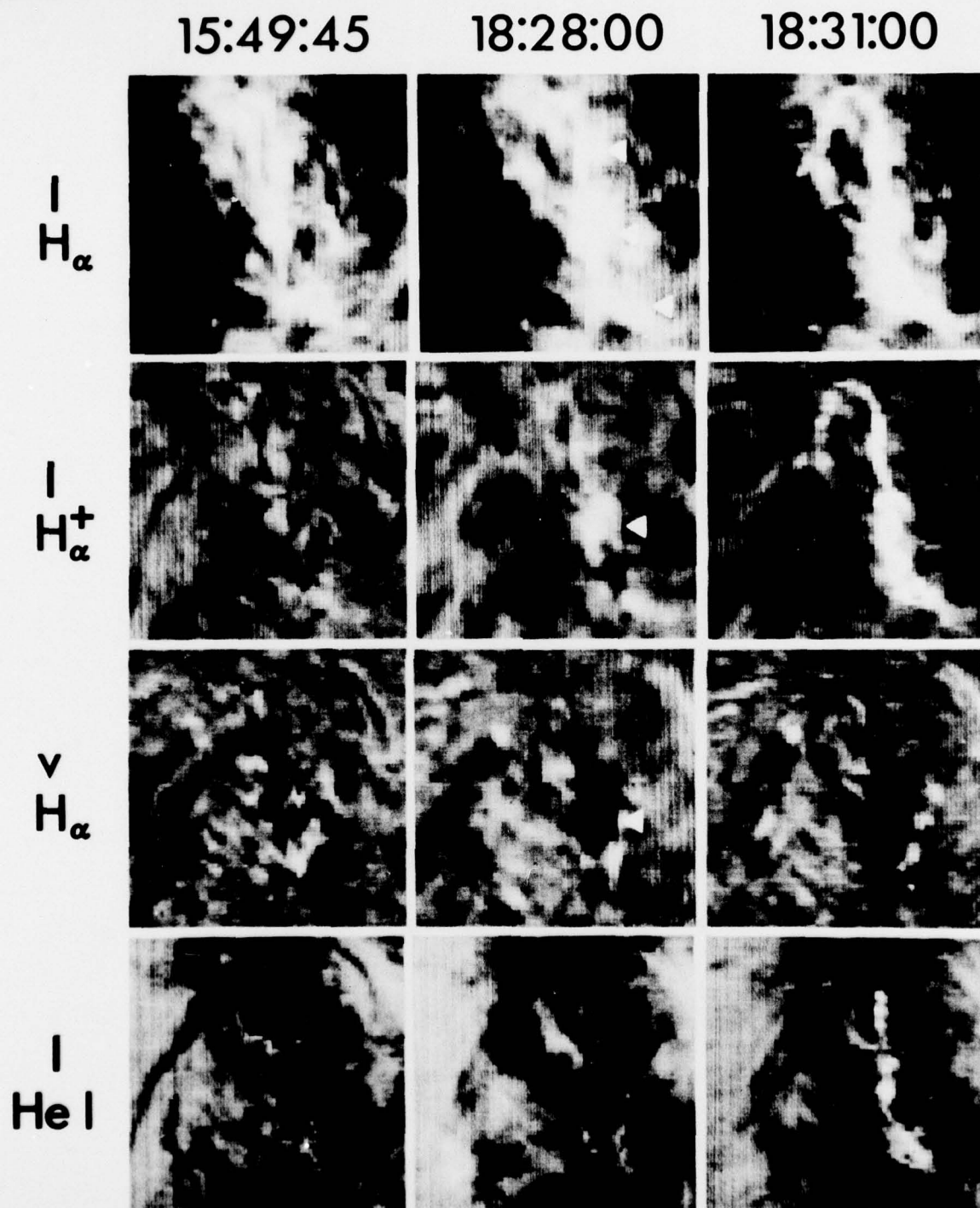


FIG. 2.—Row 1, H_{α} line-center intensity. Row 2, intensity in the red wing of H_{α} , 0.6 \AA from line center. Row 3, velocity derived from the wings of H_{α} , $\pm 0.6 \text{ \AA}$ from line center. Row 4, $He \lambda 10830$, subtraction of nearby continuum from line-center intensity (hence the disappearance of sunspot structures). Column 1, 15:49:45 UT; Column 2, 18:28:00 UT; Column 3, 18:31:00 UT. (Sacramento Peak Observatory, Air Force Geophysics Laboratory photograph.)

CANFIELD AND FISHER (see page L150)

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Air Force Geophysics Laboratory(PH)
Hanscom AFB
Massachusetts 01731

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

MAGNETIC FIELD RECONNECTION IN THE FLARE OF
18:28 UT 1975 AUGUST 10

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific, Interim.

5. AUTHOR(S) (First name, middle initial, last name)

Richard C. Canfield
Richard R. Fisher

11 6 Jul 76

12 6 p.

6. REPORT DATE

18 January 1977

7a. TOTAL NO. OF PAGES

5

7b. NO. OF REFS

11

8a. CONTRACT OR GRANT NO.

b. PROJECT, TASK, WORK UNIT NOS.

2311G302

c. DOD ELEMENT

61102F

d. DOD SUBELEMENT

9a. ORIGINATOR'S REPORT NUMBER(S)

AFGL-TR-77-0011

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

Reprinted from The Astrophysical
Journal, Vol. 210, pp L149 - L 151,
15 December 1976

12. SPONSORING MILITARY ACTIVITY

Air Force Geophysics Laboratory(PH)
Hanscom AFB
Massachusetts 01731

409 578

13. ABSTRACT

~~We discuss~~ observations of the Flare of 18:28 UT, 1975 August 10^{were} made with the Sacramento Peak Observatory 512 diode array, which simultaneously measures photospheric magnetic fields, photospheric and chromospheric velocities, and chromospheric brightness in several lines. The observations suggest triggering of the flare by emergence of new magnetic flux, as well as the geometry of the reconnected field during the flare. ~~We discuss the~~ implications of ~~our~~ observations regarding the site of the initial instability, as well as the relationship to X-ray observations. ~~are discussed.~~

KEYWORDS: Sun: flares - Sun: magnetic fields